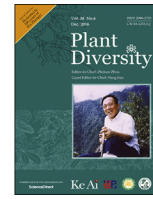
Plant Diversity 38 (2016) 295–302

Contents lists available at ScienceDirect

Plant Diversity

journal homepage: http://www.keaipublishing.com/en/journals/plant-diversity/ http://journal.kib.ac.cn



Combined community ecology and floristics, a synthetic study on the upper montane evergreen broad-leaved forests in Yunnan, southwestern China

Hua Zhu*, Yong Chai, Shisun Zhou, Lichun Yan, Jipu Shi, Guoping Yang

Center for Integrative Conservation, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Xue-Fu Road 88, Kunming, Yunnan 650223, PR China

ARTICLE INFO

Article history:
Received 2 November 2016
Accepted 2 November 2016
Available online 10 November 2016

(Editor:Wenyao Liu)

Keywords:
Biogeography
Floristic composition
Montane evergreen broad-leaved forest
Physiognomy
Species diversity
Yunnan

ABSTRACT

The upper montane evergreen broad-leaved forest in Yunnan occurs mainly in the zone of persistent cloud and has a discontinuous, island-like, distribution. It is diverse, rich in endemic species, and likely to be sensitive to climate change. Six 1-ha sampling plots were established across the main distribution area of the upper montane evergreen broad-leaved forest in Yunnan. All trees with d.b.h. > 1 cm in each plot were identified. Patterns of seed plant distributions were quantified at the specific, generic and family levels. The forests are dominated by the families Fagaceae, Lauraceae, Theaceae and Magnoliaceae, but are very diverse with only a few species shared between sites. Floristic similarities at the family and generic level were high, but they were low at the specific level, with species complementarity between plots. Diversity varied greatly among sites, with greater species richness and more rare species in western Yunnan than central Yunnan. The flora is dominated by tropical biogeographical elements, mainly the pantropic and the tropical Asian distributions at the family and genus levels. In contrast, at the species level, the flora is dominated by the southwest or the southeast China distributions, including Yunnan endemics. This suggests that the flora of the upper montane forest in Yunnan could have a tropical floristic origin, and has adapted to cooler temperatures with the uplift of the Himalayas. Due to great sensitivity to climate, high endemism and species complementarity, as well as the discontinuous, island-like, distribution patterns of the upper montane forest in Yunnan, the regional conservation of the forest is especially needed.

1. Introduction

Yunnan Province of southwestern China lies between 21°09′ and 29°15′ N, 97°32′ and 106°12′ E, and occupies an area of 394,100 km^2. It has a mountainous topography with mountain ridges generally running in a north-south direction, decreasing in elevation southward. Its elevation ranges from 76.4 m at the lowest valley bottom in the southeast (Red River) to 6740 m at the highest mountain summit in the northwest. Yunnan is extremely diverse in habitats and topography. The general climatic pattern consists of tropical wet climates in the southern lowlands, tropical dry climates in deep valleys below 1000 m alt. due to the Foehn effect, subtropical climates on the central plateau, and temperate to cold temperate climates in the northern high mountains.

Several comprehensive vegetation studies in Yunnan (Wu, 1987; Shimizu, 1991; Jin, 1979, 1992) have also been published. Previously, the evergreen broad-leaved forest was treated as a vegetation type in the vegetation classification of Yunnan (Wu, 1980, 1987). The upper montane evergreen broad-leaved forest was classified into the type of mid-montane wet evergreen broad-leaved forest (Jin, 1979).

The upper montane evergreen broad-leaved forest in Yunnan is a species-rich vegetation type and of important significance in the ecosystem and conservation. Aside from several works on community characteristics (Meng et al., 2013) and species composition (Yang et al., 2010) based on one site plot survey, there have been fewer studies on the upper montane forests in Yunnan. Due to geographical isolation and habitat heterogeneity, the floristic

* Corresponding author. Fax: +86 871 5160916.
E-mail address: zhuh@xtbg.ac.cn (H. Zhu).
Peer review under responsibility of Editorial Office of Plant Diversity

http://dx.doi.org/10.1016/j.pld.2016.11.001
2468-2659/

composition, species diversity and vegetation structure of this kind of forest has conspicuous variation across its distribution area. Studies on single plots can give limited information (Peng and Wu, 1998; Wang and Peng, 2004; Liu and Peng, 2007; Gong et al., 2011). To provide a better understanding of this kind of forest, we established six 1-ha plots across the main distribution area of the upper montane evergreen broad-leaved forest in Yunnan.

The upper montane evergreen broad-leaved forest in Yunnan has been likened to cloud forests or mossy forests of Asia (Shi and Zhu, 2009). Studies on cloud forests have mainly been done in tropical America, especially focusing on the Mexican montane forests (Alcántara et al., 2002; Cavelier et al., 1996; Hamilton et al., 1994; Kapos and Tanner, 1985; Kelly et al., 1994; Luna-Vega et al., 2001; Nadkarni et al., 1995; Sugden, 1982; Torre-Cuadros et al., 2007; Williams-Linera, 2002; Williams-Linera et al., 2005), while relatively few studies have been conducted in SE Asia (Aiba and Kitayama, 1999; Bruijnzeel et al., 1993; Meijer, 1959; Ohsawa, 1991; Sakhan et al., 2002).

As a new attempt, community ecology and floristics were combined in vegetation studies by Wu Zhengyi in his huge works (Wu, 1980, 1987). Recently, this integrated approach has successfully been used in the tropical forest studies in southern Yunnan to clarify the nature of vegetation types (Zhu, 1997, 2004, 2008; Zhu et al., 1998, 2005, 2006a,b, 2015a,b). In this article, the combination of community ecology and floristics are used to explore the physiognomy, species composition, plant diversity and biogeography of the forest, and to provide suggestions for its conservation.

2. Methods

Six 1-ha sampling plots were established in well-conserved forest patches across the main distribution area of the upper montane evergreen broad-leaved forest in Yunnan (Fig. 1), among them three are located in western Yunnan and three in central Yunnan. Our plots were selected in currently well-conserved patches of the forest (it is impossible to design well-distributed sampling plots according to normative latitude and altitude in Yunnan due to the complicated topography and serious human disturbances). Each 1-ha sampling plot was divided into 100 10 m ′ 10 m subplots. All trees with d.b.h. > 1 cm in each plot were identified and their d.b.h. and height measured. Importance value indices (IVI) (Curtis and McIntosh, 1951) were calculated for each tree species in the six 1-ha plots (IVI = Relative abundance + Relative dominance + Relative frequency). In each 1-ha sampling plot, importance value indices at family level were calculated by the sum of all species in this family. Shannon–Wiener index ($H' = -\Sigma(P_i * \ln P_i)$) and Simpson's diversity index ($D = 1 - \Sigma Pi^2$) for species diversity were calculated from the plot data. Species authorities follow *Flora Reipublicae Popularis Sinicae* (*Flora of China*). Patterns of seed plant distributions were quantified at the specific level from data in the Flora of China, at the generic level based on Wu's documentation (1991) and at the family level following Wu et al. (2003). Comparisons of both floristic composition and geographical elements were made to assess floristic similarities and variation in these sites, as well as to determine biogeographical affinities of the upper montane forest.

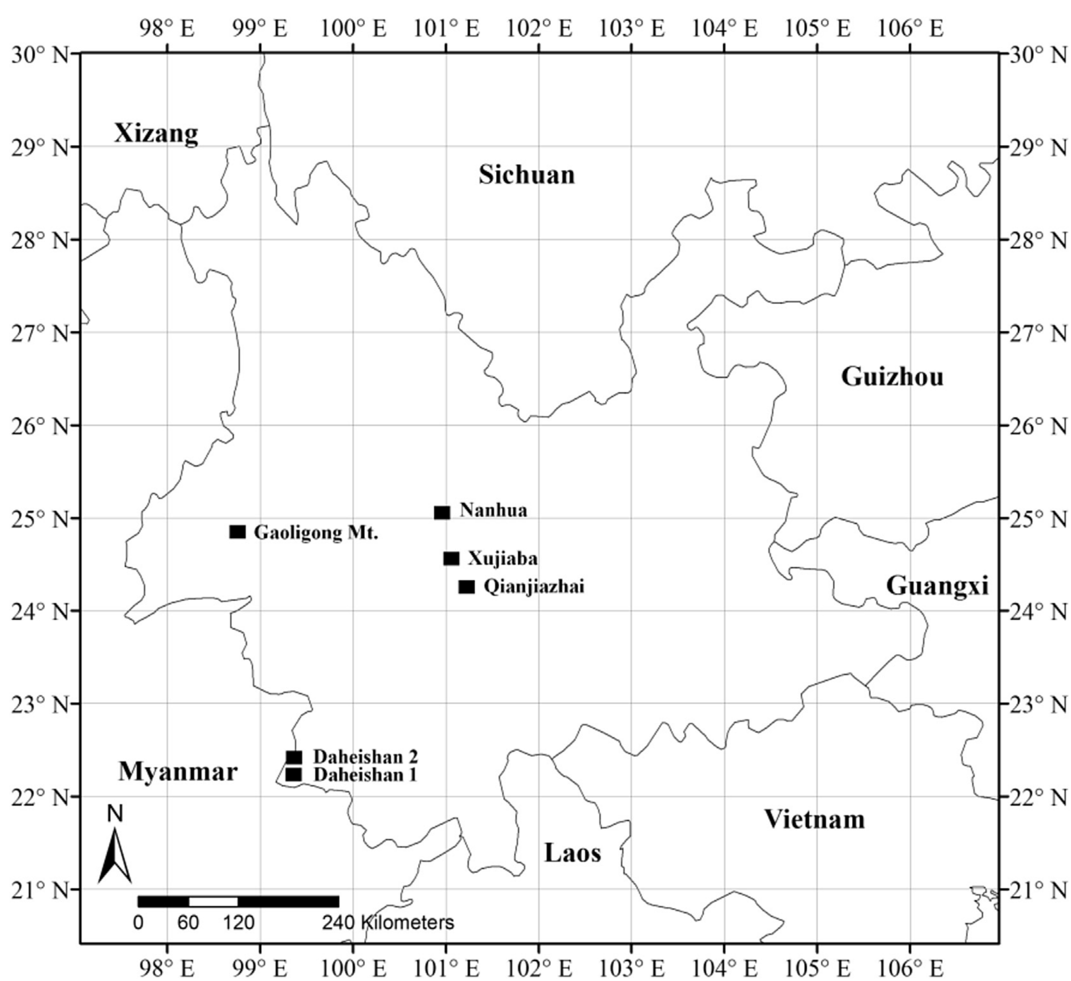


Fig. 1. Location of plot sites.

Table 1
Dominant tree species (top 30) and their important values (IVI) in the sampling plots.[a]

Daheishan I plot Location: 22° 06′ 36″ N, 99° 23′ 54″ E Alt: 2250 m Total tree species (>1 cm dbh): 88 Total stems: 3318 Shannon–Wiener's diversity indexes: 3.61614 Simpson index: 0.96259	IVI	Daheishan II plot Location: 22° 06′ 36″ N, 99° 23′ 54″ E Alt: 2300 m Total tree species (>1 cm dbh): 78 Total stems: 4930 Shannon–Wiener's diversity indexes: 3.30007 Simpson index: 0.93587	IVI	Gaoligong Mts. plot Location: 24°50′ 10″ N, 98° 45′ 53″ E Alt: 2190 m Total tree species (>1 cm dbh): 68 Total stems: 1935 Shannon–Wiener's diversity indexes: 3.60832 Simpson index: 0.96340	IVI	Qianjiazai plot Location: 24° 16′ 53″ N, 101° 15′ 53″ E Alt: 2320 m Total tree species (>1 cm dbh): 45 Total stems: 2444 Shannon–Wiener's diversity indexes: 2.73883 Simpson index: 0.89651	IVI	Xujiaba plot Location: 24°32′ 21″ N, 101°01′ 34″ E Alt: 2450 m Total tree species (>1 cm dbh): 41 Total stems: 1233 Shannon–Wiener's diversity indexes: 2.99099 Simpson index: 0.93245	IVI	Nanhua plot Location: 25°05′ 54″ N 100°55′ 9″ E Alt: 2730 m Total tree species (>1 cm dbh): 39 Total stems: 2399 Shannon–Wiener's diversity indexes: 2.43101 Simpson index: 0.86066	IVI
Helicia shweliensis	21.29	*Helicia shweliensis*	28.53	*Beilschmiedia yunnanensis*	13.77	*Lithocarpus xylocarpus*	39.14	*Castanopsis wattii*	33.57	*Castanopsis orthacantha*	80.35
Nyssa javanica	15.38	*Laurocerasus undulata*	19.79	*Neolitsea lunglingensis*	13.61	*Camellia taliensis*	35.88	*Schima noronhae*	31.13	*Vaccinium duclouxii*	32.50
Turpinia cochinchinensis	15.18	*Manglietia hookeri*	17.62	*Eurya pseudocerasifera*	13.21	*Litsea honghoensis*	30.15	*Lithocarpus xylocarpus*	25.24	*Rhododendron delavayi*	23.67
Castanopsis fleuryi	14.68	*Lithocarpus xylocarpus*	12.75	*Laurocerasus undulata*	12.2	*Manglietia insignis*	28.77	*Camellia forrestii*	25.06	*Lithocarpus hancei*	20.69
Lithocarpus magneinii	14.43	*Litsea chinpingensis*	11.99	*Lithocarpus hancei*	10.95	*Castanopsis wattii*	18.13	*Machilus bombycina*	21.74	*Lithocarpus variolosus*	18.68
Beilschmiedia glauca	13.58	*Syzygium brachythyrsum*	11.29	*Lithocarpus petelotii*	9.75	*Mahonia duclouxiana*	15.10	*Ilex gintungensis*	18.33	*Lyonia ovalifolia*	16.97
Neolitsea homilantha	12.67	*Myrsine semiserrata*	9.69	*Symplocas ramosissima*	9.73	*Lithocarpus hancei*	13.91	*Symplocos anomala*	13.03	*Illicium simonsii*	12.21
Lithocarpus fenestratus	11.08	*Stewartia pteropetiolata*	8.68	*Cyclobalanopsis lamellosa*	9.03	*Actinodaphne cupularis*	13.12	*Manglietia insignis*	12.68	*Rhododendron irroratum*	9.94
Laurocerasus undulata	10.36	*Elaeocarpus decipiens*	7.92	*Symingtonia populnea*	8.82	*Camellia pitardii*	12.92	*Symplocos sumuntia*	12.4	*Ternstroemia gymnanthera*	8.20
Myrsine semiserrata	8.40	*Neocinnamomum delavayi*	7.92	*Acer pubipetiolatum*	8.78	*Laurocerasus undulata*	11.95	*Machilus yunnanensis*	12.02	*Rhododendron decorum*	7.11
Lindera latifolia	8.27	*Brassaiopsis glomerulata*	7.83	*Eurya tsaii*	8.51	*Myrsine semiserrata*	9.83	*Illicium macranthum*	11.72	*Symplocos anomala*	7.07
Castanopsis ceratacantha	8.08	*Camellia taliensis*	7.79	*Schefflera minutistellata*	8.47	*Neolitsea polycarpa*	8.52	*Stewartia pteropetiolata*	11.25	*Schima argentea*	3.82
Stewartia pteropetiolata	7.61	*Eurya handel-mazzettii*	7.60	*Huodendron biaristatum*	8.33	*Michelia floribunda*	7.68	*Symplocos ramosissima*	11.23	*Ilex forrestii*	3.70
Ilex longecaudata	7.33	*Beilschmiedia glauca*	7.54	*Cinnamomum pauciflorum*	8.25	*Cyclobalanopsis myrsinifolia*	6.55	*Eurya obliquifolia*	9.21	*Cerasus yunnanensis*	3.40
Elaeocarpus decipiens	7.29	*Ilex longecaudata*	6.87	*Alcimandra cathcartii*	8.19	*Symplocos ramosissima*	6.19	*Symplocos poilanei*	7.64	*Ilex longecaudata*	3.35
Castanopsis tcheponensis	7.27	*Lindera latifolia*	6.50	*Acer jingdongense*	8.06	*Eurya yunnanensis*	5.21	*Neolitsea chuii*	6.68	*Daphniphyllum longeracemosum*	3.16
Symplocos sumuntia	7.26	*Neolitsea homilantha*	6.27	*Lithocarpus fenestratus*	7.26	*Machilus viridis*	4.84	*Eriobotrya prinoides*	5.77	*Pinus armandii*	2.57
Litsea chinpingensis	6.15	*Schefflera hypoleuca*	6.01	*Myrsine semiserrata*	6.67	*Eriobotrya bengalensis*	4.07	*Meliosma arnottiana*	4.71	*Eurya handel-mazzettii*	2.49
Elaeocarpus braceanus	6.12	*Castanopsis fleuryi*	5.45	*Camellia saluenensis*	6.58	*Machilus viridis*	3.56	*Laurocerasus undulata*	4.52	*Styrax tonkinensis*	2.41
Eriobotrya prinoides	5.71	*Acer pubipetiolatum*	5.37	*Michelia doltsopa*	6.4	*Styrax perkinsiae*	3.33	*Neolitsea polycarpa*	4.39	*Actinodaphne forrestii*	2.39
Pyrenaria diospyricarpa	5.70	*Eurya acuminata*	5.26	*Neolitsea homilantha*	6.24	*Meliosma kirkii*	2.86	*Lithocarpus hancei*	3.31	*Cyclobalanopsis augustinii*	2.29
Alcimandra cathcartii	4.92	*Litsea elongata*	5.14	*Sloanea dasycarpa*	6.16	*Elaeocarpus japonicus*	1.77	*Michelia floribunda*	1.47	*Machilus longipedicellata*	2.17
Phoebe rufescens	4.83	*Alcimandra cathcartii*	4.78	*Manglietia insignis*	5.57	*Schefflera fengii*	1.44	*Padus perulata*	1.37	*Phoebe forrestii*	2.11
Syzygium lineatum	4.76	*Eriobotrya prinoides*	4.52	*Elaeocarpus lacunosus*	5.3	*Cerasus yunnanensis*	1.42	*Ilex manneiensis*	1.32	*Osmanthus delavayi*	2.08
Michelia floribunda	3.80	*Eriobotrya serrata*	4.46	*Camellia taliensis*	4.95	*Betula alnoides*	1.40	*Acer campbellii*	1.22	*Ilex szechwanensis*	2.04
Litsea verticillata	3.65	*Laurocerasus phaeosticta*	4.03	*Neolitsea undulatifolia*	4.66	*Skimmia arborescens*	1.07	*Ligustrum delavayanum*	1.05	*Ilex gintungensis*	2.00
Machilus robusta	3.64	*Skimmia arborescens*	3.79	*Ficus neriifolia*	4.62	*Fraxinus chinensis*	1.00	*Tetracentron sinense*	0.93	*Ilex fragilis*	1.97
Tarennoidea wallichii	3.55	*Pyrularia edulis*	3.59	*Helicia shweliensis*	4.56	*Ficus neriifolia*	0.92	*Padus napaulensis*	0.91	*Lithocarpus dealbatus*	1.88
Acer pubipetiolatum	3.45	*Cyclobalanopsis chapensis*	3.45	*Symplocos laurina*	4.48	*Ilex macrocarpa*	0.89	*Cyclobalanopsis stewardiana*	0.8	*Neocinnamomum delavayi*	1.88
Ternstroemia gymnanthera	3.30	*Vaccinium duclouxii*	3.29	*Pyrularia edulis*	4.36	*Camellia forrestii*	0.87	*Vaccinium duclouxii*	0.79	*Castanopsis delavayi*	1.79
Other 58 species	50.27	Other 48 species	54.28	Other 38 species	58.75	Other 15 species	5.86	Other 11 species	4.51	Other 9 species	15.13

[a] Daheishan I, Daheishan II, Qianjiazai and Nanhua were newly investigated by the authors, while Xujiaba was studied by Yang et al. (2010). In addition, the Gaoligong Mts. plot was abstracted from a 4-ha permanent plot investigated by Meng et al. (2013).

3. Results

3.1. Species assemblage

The upper montane evergreen broad-leaved forest in Yunnan is very diverse in species composition, even in dominant species (Table 1), although most sites are dominated by the families Fagaceae, Lauraceae, Theaceae and Magnoliaceae or Ericaceae at higher altitudinal sites (Table 2). The families Fagaceae, Lauraceae and Theaceae have the highest importance values in most plots (Table 2), followed by Magnoliaceae and Rosaceae. However, the Proteaceae has high importance values in Daheishan I and Daheishan II, while the Symplocaceae and Ericaceae have a high importance value in Xujiaba and Nanhua, respectively. Fagaceae, Lauraceae, Theaceae are the most species-rich families in all six plots, followed in most plots by Rosaceae and Araliaceae.

The two nearby plots Daheishan I and Daheishan II in western Yunnan share the dominant tree species *Helicia shweliensis*, but differ in subdominant species. In the Gaoligong Mts. plot, *Beilschmiedia yunnanensis* is the most dominant species. In the Qianjiazai plot in central Yunnan, *Lithocarpus xylocarpus* is the most dominant species, while in the Xujiaba plot at higher elevation, *Castanopsis wattii* is the most dominant species. In the Nanhua plot at the highest elevation, *Castanopsis orthacantha* is the most dominant species, followed by *Vaccinium duclouxii, Rhododendron delavayi*.

Among the top ten dominant species, none is shared by all six plots. However, among the all tree species recorded, five species, *Laurocerasus undulata, Michelia floribunda, Lithocarpus hancei, Ternstroemia gymnanthera* and *Symplocos ramosissima*, were found in five plots. *L. xylocarpus* and *Machilus yunnanensis* were found in four plots. The two nearby plots, Daheishan I and Daheishan II, share 59 species, but shared species are much less important in the other plots.

3.2. Physiognomy

The six plots covered an altitudinal range of 2190 m–2730 m, and of them three plots representing different altitudes were selected to illustrate the physiognomy of the forest.

The life forms of Daheishan I plot, Xujiaba plot and Nanhua plot were enumerated in Table 3. Daheishan I at a lower elevation has more mesophanerophytes (34.45%) and epiphytes (17.22%), less chamaephytes and herbaceous phanerophytes (6.22%), hemicryptophytes (6.22%) and geophytes (2.87%); while Nanhua at a higher elevation has more microphanerophytes (20.69%), nanophanerophytes (14.66%), and geophytes (5.17%). All three plots are dominated by tree species with mesophyllous leaves, contributing from 53.85% to 72.09% of the total tree species (Table 4). However, the ratio of microphyllous leaves show conspicuous variation with altitude. In the Nanhua plot at 2730 m above sea-level 43.59% of the total tree species have non-entire leaves and 41.03% of tree species have microphyllous leaves, while in the Daheishan I plot at 2250 m a.s.l. only 23.26% have non-entire leaves and microphyllous leaves.

3.3. Species diversity

The number of tree species >1 cm d.b.h. (diameter at breast height) in a 1-ha sampling plot was 39–88 in these upper montane forests (see Table 1). The number of species was more in the three plots in western Yunnan than in other three plots in central Yunnan. The Shannon–Weiner index showed a similar pattern to species richness. Species sequences ranked by Importance Value

Table 4
Comparisons of leaf features of tree species in three 1-ha plots.

Location	Leaf size[a]			Leaf type		Leaf margin	
	Ma %	Me %	Mi %	Single %	Compound %	Entile %	None entile %
Nanhua	5.13	53.85	41.03	100	0	56.41	43.59
Xujiaba	4.88	65.85	29.27	90.24	9.76	48.78	51.22
Daheishan I	4.65	72.09	23.26	93.02	6.89	76.74	23.26

Ma: Macrophyll; Me: Mesophyll; Mi: Microphyll.
[a] Webb (1959) split off the lower end of Raunkiaer's big mesophyll class (2025–18,225 mm^2) as notophylls (2025–4500 mm^2). Although it is better for detailing categories of leaf size spectrum, Chinese botanists are more familiar with Raunkiaer' big mesophyll class, and here we use Raunkiaer's big mesophyll class for the evergreen broad-leaved forest in Yunnan.

Table 2
Dominant families ranked by the Importance Value Index (IVI) and by species richness in the six 1-ha plots.

Daheishan I		Daheishan II		Gaoligong Mts.		Qianjiazai		Xujiaba		Nanhua	
Family ranked by IVI											
Lauraceae	67.57	Lauraceae	77.11	Lauraceae	57.25	Fagaceae	77.73	Theaceae	77.49	Fagaceae	127.26
Fagaceae	62.55	Fagaceae	35.07	Fagaceae	39.29	Lauraceae	61.82	Fagaceae	62.92	Ericaceae	90.25
Proteaceae	21.29	Theaceae	34.12	Theaceae	38.18	Theaceae	56.57	Lauraceae	46.07	Theaceae	14.51
Rosaceae	20.94	Proteaceae	28.53	Magnoliaceae	21.92	Magloniaceae	36.45	Symplococaceae	44.3	Aquifoliaceae	13.06
Theaceae	19.09	Magloniaceae	22.82	Rosaceae	17.55	Rosaceae	18.44	Aquifoliaceae	20.47	Schisandreaceae	12.21
Family ranked by number of species											
Lauraceae	25	Lauraceae	16	Lauraceae	10	Lauraceae	8	Lauraceae	7	Fagaceae	7
Fagaceae	9	Theaceae	9	Theaceae	8	Theaceae	7	Theaceae	6	Ericaceae	5
Theaceae	8	Fagaceae	8	Fagaceae	5	Fagaceae	4	Fagaceae	4	Aquifoliaceae	5
Rosaceae	5	Araliaceae	6	Araliaceae	5	Rosaceae	3	Symplococaceae	4	Lauraceae	5
Araliaceae	4	Rosaceae	4	Magnoliaceae	4	Araliaceae	3	Aquifoliaceae	4	Rosaceae	4

Table 3
Comparisons of plant life forms in three 1-ha forest plots.

Location		L	Megaph	Mesoph	Microph	Nanoph	HPH & Ch	H	G	Ep	Sa	Total
Nanhua (2730 m alt.)	No. of species	16	0	22	24	17	13	13	6	6	0	116
	%	13.79	0.00	18.97	20.69	14.66	11.21	11.21	5.17	5.17	0.00	100.00
Xujiiaba (2450 m alt.)	No. of species	18	1	44	12	9	28	21	7	22	2	164
	%	10.98	0.61	26.83	7.32	5.49	17.07	12.80	4.27	13.41	1.22	100.00
Daheishan I (2250 m alt.)	No. of species	26	3	72	16	15	13	15	6	36	7	209
	%	12.44	1.44	34.45	7.66	7.18	6.22	6.22	2.87	17.22	3.35	100.00

L: Liana; Megaph: Megaphanerophytes; Mesoph: Mesophanerophytes; Microph: Microphanerophytes; Nanoph: Nanophanerophytes; HPH & Ch: Chamaephytes & Herbaceous phanerophytes; G: Geophytes; H: Hemicryptophytes; Ep: Epiphytes; Sa: Sarpophytes (Raunkiaer (1934) revised by Mueller-Dombois and Ellenberg, 1974).

Index (IVI) of the six forest plots showed the presence of more rare species in the three plots in western Yunnan (Fig. 2). Species sequences ranked by stems of the six plots showed the same patterns as the species sequences ranked by IVI: the presence of more rare species in the three plots in western Yunnan (Fig. 3).

3.4. Floristic analysis

A total of 219 tree species in 91 genera and 41 families were recorded from the six 1-ha plots. Eight geographical elements at the family level were recognized, of which the pantropic distribution is the most dominant element, accounting for 36.59% of the total families, followed by the north temperate distribution (Table 5). All tropical families together made up 53.66%, while all temperate families together made up 31.71% of total families. At the generic level, 13 geographical elements were recognized, of which the tropical Asian genera contributed 27.47%, followed by the pantropic genera (13.19%), and the east Asia and north America disjunct genera (14.29%), as well as the north temperate genera (12.09%) (Table 5). All tropical elements together made up 59.34% of the total genera, and all temperate elements made up 38.46%. Clearly, at both the family and the genus levels, tropical elements were dominant. At the species level, however, elements from southwest or southeast China, including Yunnan, have the highest percentage, accounting for 44.29% of the total species, followed by the species with south Asia to mainland southeast Asia (SE Himalaya) distributions, which accounted for 26.94%.

3.5. Species complementarity

Floristic similarities between plots are high at the family and generic levels, but low at the species level (Table 6), with the exception of Daheishan I and Daheishan II. Species-level similarities decline with separation distance. Species complementarity between plots is conspicuous.

4. Discussion

The upper montane evergreen broad-leaved forest in Yunnan is dominated by the families Fagaceae, Lauraceae, Theaceae and Magnoliaceae. However, it is very diverse in species. Only five species were found in common in five of the six plots, and none of these are dominants. Floristic similarities at the family and generic levels were high, but low at the species level, demonstrating species complementarity across plots. One possible explanation could be that upper montane evergreen broad-leaved forest areas in Yunnan were quickly uplifted with the Himalayas during the Quaternary period, while the common Tertiary flora underwent conspicuously rapid speciation in response to the quick uplift of the mountains.

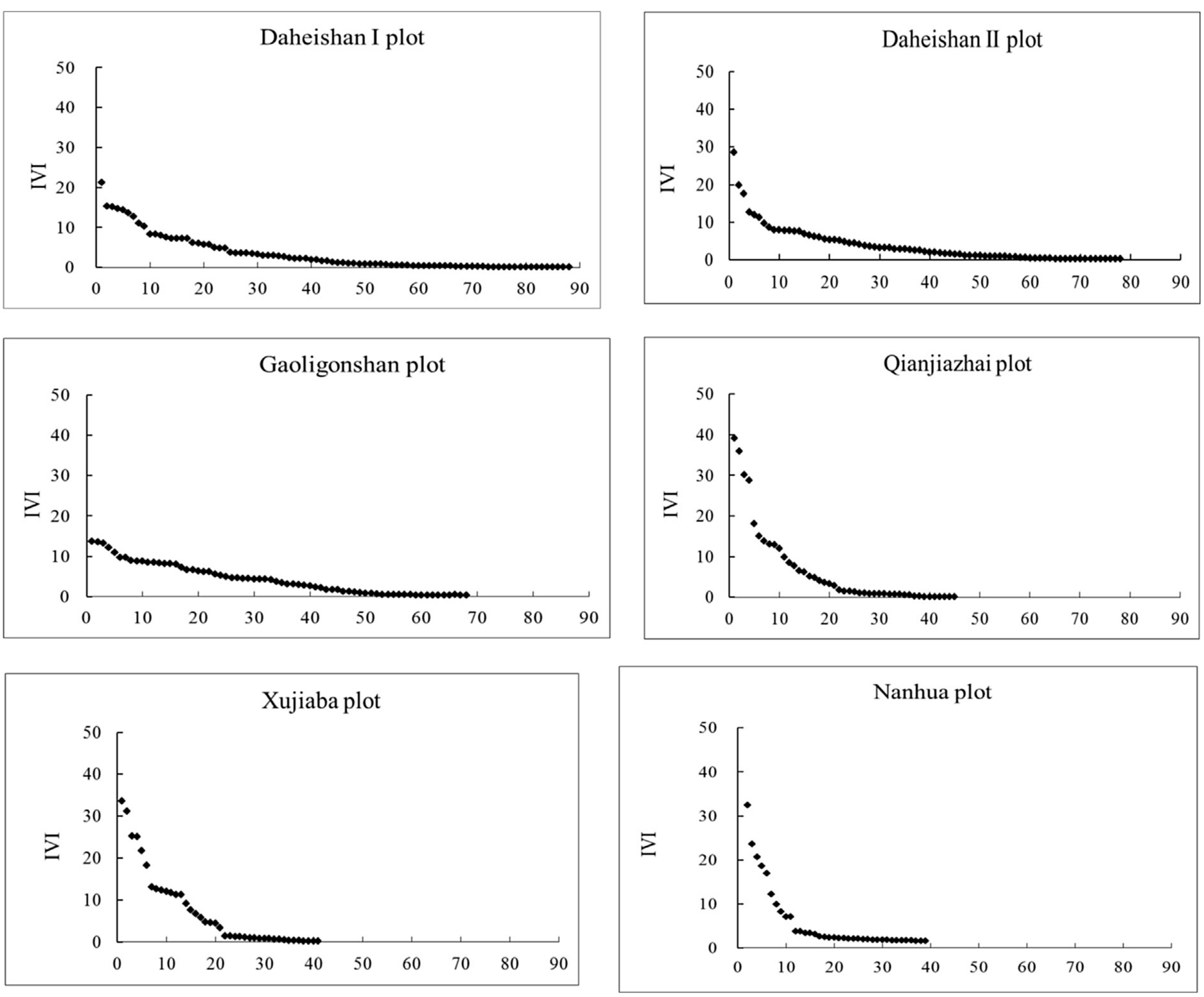


Fig. 2. Species sequences ranked by IVI of the six forest plots.

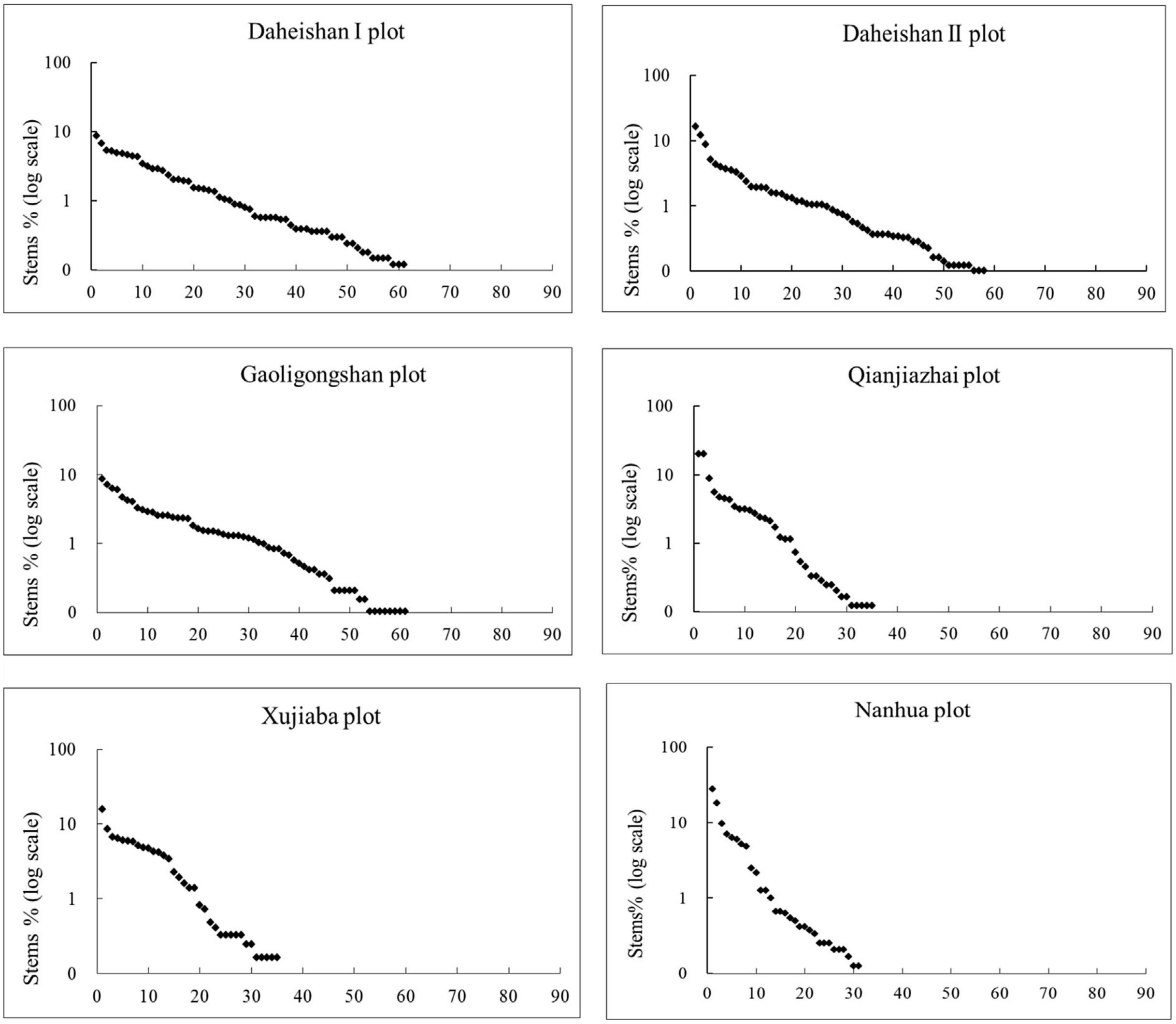


Fig. 3. Species sequences ranked by stems % (log scale) of the six forest plots.

Species richness was higher in the three plots in western Yunnan than in the three plots in central Yunnan. Species sequence patterns show the presence of more rare species in the three plots in western Yunnan. Charcoal was frequently found in the soil during our field survey in central Yunnan, suggesting a possibly long history of anthropogenic fires, which would explain the lower richness. The large areas of pine forest dominated by the fire-tolerant *Pinus yunnanensis* in central Yunnan support this historical explanation (Tang et al., 2013).

Yunnan has a similar latitude and mountain topography to Mexico. The Mexican cloud forests have a wider distribution range, from 600 m to 3000 m a.s.l., but optimally between 1200 m and 2450 m (Alcántara et al., 2002). The montane forests in Yunnan occur in a relatively narrow range from 2100 m to 2900 m a.s.l., and have a generally higher altitudinal distribution. It could be related to the large uplift of the Himalayas and be affected by the '*Massenerhebung*' effect (Grubb, 1971; Bruijnzeel et al., 1993). The Mexican cloud forests are characterized by species in the genera *Clethra, Magnolia, Meliosma, Styrax, Symplocos* and *Ternstroemia* (Alcántara et al., 2002). The upper montane forests in Yunnan have the same six genera as Mexico, although they are not dominant. In a 1-ha plot of tropical montane forest in Peru, trees with dbh >10 cm belonging to 135 species, 66 genera and 35 families were recorded (Torre-Cuadros et al., 2007). In our plots, tree species >1 cm dbh in a 1-ha sampling plot included 39–88 species, 28–55 genera and 15–31 families. Although the species richness varies conspicuously from place to place in tropical America, floristic richness of the montane forest in Yunnan looks lower than that in American montane forests.

Studies on tropical montane forests in tropical America suggested that similar elevation and environmental conditions do not dictate similar structure and floristics (Nadkarni et al., 1995). They have great heterogeneity in species composition and vegetation structure over short geographical distances (Williams-Linera, 2002). This is supported by our work in Yunnan, which shows conspicuous floristic variation occurs among the six plots. In the fragments of Mexican montane forests, species composition was different, but complementary. The similarity in species was low between fragments, and species turnover between sites was very high, with complementarities between pairs of sites higher than 50% in all cases (Williams-Linera, 2002; Williams-Linera et al., 2005). In the montane forest in Yunnan, as in the fragments of Mexican montane forests, the species similarity is low and species complementarity is conspicuous between plots in separate sites.

The flora of the tropical American montane forests was suggested to be a blend of Neotropical elements that have adapted to

Table 5
Composition of geographical elements at the family, genus and species levels.

Geographical elements at family level	Number of families	%
Cosmopolitan	6	14.63
Pantropic	15	36.59
Tropical Asia and tropical America disjunct	5	12.20
Tropical Asia to tropical Australia	1	2.44
Tropical Asia	1	2.44
(Tropical in total)	**(22)**	**(53.66)**
North temperate	8	19.51
East Asia and north America disjunct	3	7.32
East Asia	2	4.88
(Temperate in total)	**(12)**	**(31.71)**
Total number of families	41	100
Geographical elements at genus level	**Number of genera**	**%**
Cosmopolitan	2	2.20
Pantropic	12	13.19
Tropical Asia and tropical America disjunct	8	8.79
Old world tropic	3	3.30
Tropical Asia to tropical Australia	3	3.30
Tropical Asia to tropical Africa	3	3.30
Tropical Asia	25	27.47
(Tropical in total)	**(54)**	**(59.34)**
North temperate	11	12.09
East Asia and North America disjunct	13	14.29
Old world temperate	1	1.10
Mediterranean, W Asia to C Asia	1	1.10
East Asia	7	7.69
Endemic to China	2	2.20
(Temperate in total)	**(35)**	**(38.46)**
Total number of genera	91	100.00
Geographical elements at species level	**Number of species**	**%**
East Asia	11	5.02
SW or to SE China including Yunnan	97	44.29
S Asia to Mainland SE Asia (SE Himalaya)	59	26.94
Mainland SE Asia to S China	26	11.87
India–Malaysia	26	11.87
Total number of species	219	100.00

cooler temperatures with temperate elements that have immigrated from both boreal and austral regions (Gentry, 1982; Kelly et al., 1994). In the flora of the upper montane forest in Yunnan, tropical elements are dominant at both the family and the genus levels, which suggests that the flora could also have a tropical floristic origin. At the species level, however, elements from southwest or southeast China, including Yunnan, are represented by the highest percentage (Zhu, 2016). It is possible that the flora in Yunnan could have originated from a tropical lowland flora, and these tropical elements have since adapted to cooler temperatures with uplift of the Himalayas; subsequently, temperate elements immigrated from the north temperate and east Asian regions, and rapid speciation occurred with the rising elevation of this region (Zhu, 2012).

5. Conservation implications

Montane cloud forests are sensitive to climate (Foster, 2001). They are very rich in epiphytic species, which are sensitive to air humidity and are considered excellent environmental indicators (Li et al., 2013). They are also strongly linked to regular cycles of cloud formation (Still et al., 1999). The upper montane forest in Yunnan has high endemism and a great sensitivity to climate. The conservation of the upper montane forest against globe warming is exceptionally important. Due to geographical isolation and habitat heterogeneity, the floristic composition and species diversity of this kind of forest display variation across its distribution area and species complementarity is high. The regional conservation of the upper montane forest, not just of several sites, is therefore needed. The plots in western Yunnan have more species richness and more rare species than the plots in central Yunnan. Therefore, it is also important to pay more attention to the upper montane forest in western Yunnan for conservation.

6. Conclusion

The upper montane forest in Yunnan is dominated by the families Fagaceae, Lauraceae, Theaceae and Magnoliaceae, but is very diverse in species. Only a few species were shared between separate sites. Floristic similarities at the family and generic level were high, but they were low at the specific level, with species complementarity between plots. Diversity varied greatly among sites, with both species richness and rare species more in western

Table 6
Comparison of floristic similarities at the family, generic and specific levels between these plots.

Compared plots	Daheishan I	Daheishan II	Gaoligong	Qianjiazhai	Xujiaba	Nanhua
	Shared/similarity coefficient (%)[a]	Shared/similarity coefficient (%)	Shared/similarity coefficient (%)	Shared/similarity coefficient (%)	Shared/similarity coefficient (%)	Shared/similarity coefficient (%)
Similarity coefficients at family level						
Daheishan I	100/100					
Daheishan I	27/90					
Gaoligon	25/83.33	24/80	100/100			
Qianjiazhai	16/84.21	16/84.21	16/84.21	100/100		
Xujiaba	11/73.33	13/86.67	12/80	12/84.21	100/100	
Nanhua	10/66.67	12/80	12/80	11/73.33	10/66.67	100/100
Similarity coefficients at generic level						
Daheishan 1	100/100					
Daheishan 2	47/85.45	100/100				
Gaoligon	31/60.78	31/60.78	100/100			
Qianjiazhai	27/75	29/80.56	24/66.67	100/100		
Xujiaba	20/71.43	24/85.71	18/64.29	22/78.57	100/100	
Nanhua	15/53.57	16/57.14	14/50	16/57.14	13/46.43	100/100
Similarity coefficients at specific level						
Daheishan 1	100/100					
Daheishan 2	59/75.64	100/100				
Gaoligon	16/23.53	17/25	100/100			
Qianjiazhai	10/22.73	13/29.55	8/18.18	100/100		
Xujiaba	10/24.39	16/39.02	5/12.2	17/41.46	100/100	
Nanhua	9/23.08	10/25.64	4/10.25	6/15.38	5/12.82	100/100

[a] Similarity coefficient between A and B = the number of taxa shared by both A and B divided by the lowest number of taxa of A or B, multiplied by 100%.

Yunnan than central Yunnan, suggesting a the possibility of a long history of anthropogenic disturbance in central Yunnan. The flora is dominated by tropical biogeographical elements, mainly the pantropic and the tropical Asian distributions at the family and genus levels, but the southwest or to southeast China distribution, including Yunnan endemics at the species level. This suggests that the flora of the upper montane forest in Yunnan could have a tropical floristic origin, and has adapted to cooler temperatures with the uplift of the Himalayas, and then undergone rapid speciation in response to the rising elevation of this region. Regional conservation of these forests is needed due to a number of factors: high sensitivity to climate; high endemism and species complementarity; as well as discontinuous, island-like distributions.

Acknowledgments

This research was supported by the National Natural Science Foundation of China, No. 41471051, 41071040, 31170195. Prof. Richard Corlett helped improve the English of the article.

References

Aiba, S., Kitayama, K., 1999. Structure, composition and species diversity in an altitude-substrate matrix of rain forest tree communities on mount Kinabalu, Borneo. Plant Ecol. 140 (2), 139–157.

Alcántara, O., Luna, I., Velázquez, A., 2002. Altitudinal distribution patterns of Mexican cloud forests based upon preferential characteristic genera. Plant Ecol. 161, 167–174.

Bruijnzeel, L.A., Waterloo, M.J., Proctor, J., Kuiters, A.T., Kotterink, B., 1993. Hydrological observations in montane rain forests on Gunung Silam, Sabah, Malaysia, with special reference to the 'Massenerhebung' effect. J. Ecol. 81, 145–167.

Cavelier, J., Solos, D., Jaramillo, M.A., 1996. Fog interception in montane forests across the certral Cordillera of Panama. J. Trop. Ecol. 12, 357–369.

Curtis, J.T., McIntosh, R.P., 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology 32, 467–496.

Foster, P., 2001. The potential negative impacts of global climate change on tropical montane cloud forests. Earth Sci. Rev. 55, 73–106.

Gentry, A.H., 1982. Neotropical floristic diversity: phytogeographical connections between central and south America, Pleistocene climatic fluctuations, or an accident of the Andean Orogeny. Ann. Mo. Bot. Gard. 69, 557–593.

Gong, H.D., Yang, G.P., Lu, Z.Y., Liu, Y.H., 2011. Diversity and spatial distribution patterns of trees in an evergreen broad-leaved forest in the Ailao Mountains, Yunnan. Biodivers. Sci. 19 (2), 143–150.

Grubb, P.J., 1971. Interpretation of the *Massenerhebung*' effect on tropical mountains. Nature 229 (1), 44–45.

Hamilton, L.S., Juvik, J.O., Scatena, F.N., 1994. Tropical Montane Cloud Forest. Ecological Studies 110. Springer, New York, USA.

Jin, Z.Z., 1979. The types and characteristics of evergreen broad-leaved forests in Yunnan. Acta Bot. Yun 1 (1), 90–105 (in Chinese with English abstract).

Jin, Z.Z., 1992. The natural vegetation types of Yunnan, China. A series of geobotanical monographs. Braun-Blanquetia 8, 65–76.

Kapos, V., Tanner, E.V.J., 1985. Water relations of Jamaican upper montane rain forest trees. Ecology 66, 241–250.

Kelly, D.L., Tanner, E.V.J., Lughadha, E.M.N., 1994. Floristics and biogeography of a rain forest in the Venezuelan Andes. J. Biogeogr. 21, 421–440.

Li, S., Liu, W.Y., Li, D.W., 2013. Bole epiphytic lichens as potential indicators of environmental change in subtropical forest ecosystems in southwest China. Ecol. Indic. 29, 93–104.

Liu, E.D., Peng, H., 2007. A preliminary floristic study on the mid-montane humid evergreen broad-leaved forest in Yongde Snow Mountain, SW Yunnan, China. Acta Bot. Yunn 29 (2), 129–136.

Luna-Vega, I., Morrone, J.J., Ayala, O.A., Organista, E.D., 2001. Biogeographical affinities among Neotropical cloud forest. Plant Syst. Evol. 228, 229–239.

Meijer, W., 1959. Plant sociological analysis of montane rain forest near Tjibodas, West Java. Acta Bot. Neerl. 8, 277–291.

Meng, G.Z., Chai, Y., Yuan, M.C., Ai, H.S., Li, G.X., Wang, Q., Li, P.R., Lin, R.T., 2013. Community characteristics of the mid-montane humid evergreen broad-leaved forest in Gaoligong Mountains, Yunnan. Sci. Silvae Sin. 49 (3), 144–151.

Mueller-Dombois, D., Ellenberg, H., 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons.

Nadkarni, N., Matelson, T.J., Haber, W.A., 1995. Structural characteristics and floristic composition of a Neotropical cloud forest, Monteverde, Costa Rica. J. Trop. Ecol. 11, 481–495.

Ohsawa, M., 1991. Structural comparison of tropical montane rain forests along latitudinal and altitudinal gradients in south and east Asia. Vegetatio 97, 1–10.

Peng, H., Wu, Z.Y., 1998. The preliminary floristical study on mid-montane humid evergreen broad-leaved forest in Mt. Wuliangshan. Acta Bot. Yunn 20 (1), 12–22.

Raunkiaer, C., 1934. The Life Forms of Plants and Statistical Plant Geography. Oxford University Press, Oxford.

Sakhan, T., Pongsak, S., Katsutoshi, S., Witchaphart, S., 2002. Forest structure and tree species diversity along an altitudinal gradient in Doi Inthanon National Park, Northern Thailand. Tropics 12 (2), 85–102.

Shi, J.P., Zhu, H., 2009. Tree species composition and diversity of tropical mountain cloud forest in the Yunnan, southwestern China. Ecol. Res. 24, 83–92.

Shimizu, Y., 1991. Forest types and vegetation zones of Yunnan, China. J Fac. Sci Univ Tokyo Sect III 15, 1–71.

Still, C.J., Foster, P.N., Schneider, S.H., 1999. Simulating the effects of climate change on tropical montane cloud forests. Nature 398, 608–610.

Sugden, A.M., 1982. The ecological, geographic and taxonomic relationships of the flora of an isolated Colombian cloud forest with some implications for island biogeography. J. Arnold Arbor. 63, 31–61.

Tang, C.T., He, L.Y., Su, W.H., Zhang, G.F., Wang, H.C., Peng, M.C., Wu, Z.L., Wang, C.Y., 2013. Regeneration, recovery and succession of a *Pinus yunnanensis* community five years after a mega-fire in central Yunnan, China. For. Ecol. Manag. 294, 188–196.

Torre-Cuadros, MÁLa, Herrando-Pérez, S., Young, K.R., 2007. Diversity and structural patterns for tropical montane and premontane forests of central Peru, with an assessment of the use of higher-taxon surrogacy. Biodivers. Conserv. 16, 2965–2988.

Wang, L.S., Peng, H., 2004. The preliminary floristic study on the elements of *Lithocarpus variolosa* forest in Mt. Xiaobaicaoling, C. Yunnan. Acta Bota Yunn 26 (2), 157–165.

Webb, L.J., 1959. A physiognomic classification of Australian rain forests. J. Ecol. 47, 551–570.

Williams-Linera, G., 2002. Tree species richness complementarily, disturbance and fragmentation in a Mexican tropical montane cloud forest. Biodivers. Conserv. 11, 1825–1843.

Williams-Linera, G., Palacios-Rios, M., Hernández-Gómez, R., 2005. Fern richness, tree species surrogacy, and fragment complementarity in a Mexican tropical montane cloud forest. Biodivers. Conserv. 14, 119–133.

Wu, Z.Y., 1980. V*egetation of China*. Science Press, Beijing, pp. 363–379 (in Chinese).

Wu, Z.Y., 1987. Vegetation of Yunnan. Science Press, Beijing, pp. 97–143 (in Chinese).

Wu, Z.Y., 1991. The areal-types of Chinese genera of seed plants. Acta Bot. Yun Supp IV, 1–139 (in Chinese with English abstract).

Wu, Z.Y., Zhou, Z.K., Li, D.Z., Peng, H., Sun, H., 2003. The areal-types of the world families of seed plants. Acta Bot. Yun 25, 245–257 (In Chinese with English abstract).

Yang, G.P., Zheng, Z., Zhang, Y.P., Liu, Y.H., Gong, H.D., Lu, Z.Y., 2010. Community characteristics of middle mountain moist evergreen broad-leaved forest in Ailao Mountains. J Northeast For Univ 38 (9), 16–19 (In Chinese with English abstract).

Zhu, H., 1997. Ecological and biogeographical studies on the tropical rain forest of south Yunnan, SW China with a special reference to its relation with rain forests of tropical Asia. J. Biogeogr. 24, 647–662.

Zhu, H., 2004. A tropical seasonal rain forest at its altitudinal and latitudinal limits in southern Yunnan, SW China. Gardens' Bull. Singap. 56, 55–72.

Zhu, H., 2008. Advances in biogeography of the tropical rainforest in southern Yunnan, southwestern China. Trop. Conserv. Sci. 1, 34–42.

Zhu, H., 2012. Biogeographical divergence of the flora of Yunnan, southwestern China initiated by the uplift of Himalaya and extrusion of indochina block. PLoS One 7 (9), e45601.

Zhu, H., 2016. A discussion on the origin of the mid-montane wet evergreen broad-leaved forest in Yunnan. Plant Sci. J. 34 (5).

Zhu, H., Wang, H., Li, B.G., 1998. The structure, species composition and diversity of the limestone vegetation in Xishuangbanna, SW China. Gardens' Bull. Singap. 50, 5–33.

Zhu, H., Shi, J.P., Zhao, C.J., 2005. Species composition, physiognomy and plant diversity of the tropical montane evergreen broad-leaved forest in southern Yunnan. Biodivers. Conserv. 14, 2855–2870.

Zhu, H., Cao, M., Hu, H.B., 2006a. Geological history, flora, and vegetation of Xishuangbanna, southern Yunnan, China. Biotropica 38 (3), 310–317.

Zhu, H., Wang, H., Li, B.G., 2006b. Species composition and biogeography of tropical montane rain forest in southern Yunnan of China. Gardens' Bull. Singap. 58, 81–132.

Zhu, H., Chai, Y., Zhou, S.S., Wang, H., Yan, L.C., 2015a. Vegetation, floristic composition and species diversity in a tropical mountain nature reserve in southern Yunnan, SW China with implications to conservation. Trop. Conserv. Sci. 8 (2), 528–546.

Zhu, H., Wang, H., Li, B.G., Zhou, S.S., Zhang, J.H., 2015b. Studies on the forest vegetation of Xishuangbanna. Plant Sci. Jour 33 (5), 641–726.